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NORTHERN MINING PROBLEMS WITH PARTICULAR REFERENCE TO UNIT OPERATIONS IN PERMAFROST

AMIL DUBNIE

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NORTHERN MINING PROBLEMS WITH PARTICULAR REFERENCE TO UNIT OPERATIONS IN PERMAFROST

by

Amil Dubnie*

ABSTRACT

As transportation facilities improve, the economics of northern mining will be favourably affected and substantially more mines will be operated. Many of the mines may be located in permafrost, but, so far, few Canadian studies of mining within such an environment have been made.

Surface miners have already learned how to operate in the North, and, through trial and error, modifications to equipment and to the conditions for personnel have enabled year-round operation. However, efficient fragmenting of frozen rock may be one area where methodical research may reduce the costs to northern operations.

Underground miners have applied southern methods to northern mining with only minor modifications. This may have led to higher mining costs than necessary, but owing to other major problems (i.e. transportation) they may have been obscured. The possibility of developing new concepts for northern mining, whereby the environment would be preserved to utilize whatever advantages it may present, has not received attention.

This report discusses research in many areas of northern mining such as: the evaluation of supports in access openings and stopes in permafrost; the use of frozen fills as support; the environmental effects of dry mining; the techniques of ice control in access openings.

Key Words: North, Mining, Permafrost, Ice.

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PROBLEMES MINIERS DANS LE NORD AVEC REFERENCE PARTICULIERE DES CHANTIERS D'EXPLOITATION DANS LE PERMAFROST

par

Amil Dubnie*

RESUME

Lorsque les facilités de transport s'amélioreront, la politique économique de l'industrie minière dans le Nord sera mieux disposée, et donc, plus de mines seront installées d'une manière substantielle. Plusieurs des mines sont situées dans le permafrost, mais, jusqu'à date, il y a eu peu d'études minières faites par des Canadiens dans un tel milieu.

Les mineurs de l'exploitation à ciel ouvert ont déjà appris comment s'installer dans le Nord, et c'est à force de procéder par tâtonnements pour modifier l'équipement et améliorer les conditions de vie pour le personnel, que l'entreprise peut être en vigueur durant toute l'année. Cependant, un domaine dans lequel une recherche méthodique pourrait réduire le coût de l'industrie minière dans le Nord, est celui de la fragmentation efficace des roches gelées.

Les mineurs souterrains ont fait l'application des méthodes du Sud avec des modifications mineures pour l'industrie minière dans le Nord. Ceci peut avoir causé une hausse dans le coût de l'installation, mais à cause d'un certain nombre de problèmes majeurs (tels que la transportation), il a dû être effacé. Il n'y a pas eu d'importance jetée sur la possibilité de développer de nouveaux concepts pour l'industrie minière dans le Nord, où le milieu pourrait être préservé et où on pourrait utiliser quelques soient ses avantages.

Mots clefs: Nord, industrie minière, permafrost, glace.

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Ce rapport traite de la recherche dans plusieurs domaines de l'industrie minière dans le Nord, tels que: l'évaluation de soutènements pour accès à la mine et pour chantiers dans le permafrost; l'usage de matériaux de remblai gelés comme soutènement; les effets écologiques de l'exploitation à sec; les techniques du contrôle de la glace pour les accès à la mine.

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INTRODUCTION

There is no doubt that with further development of transportation facilities in the North, the economics of mining mineral deposits will be favourably affected. This should lead to the opening of many new mines. All of these mines will be operated in a cold climate and some may be entirely in permafrost. Although problems of construction and access in northern areas have gained considerable attention, little has been done to evaluate, in a methodical way, the problems related to mining. The conditions which may be encountered in the northern areas are indicated in Figure 1 which shows isotherms, the tree line and the tentative limits of continuous and discontinuous permafrost. Data shown in the Figure have been adapted from other sources, therefore they can be considered only as approximate.

Permafrost is the term generally applied to perennially frozen ground. The term is independent of the actual composition of the ground which may be organic terrain (muskeg), soil, gravel, rock, etc. Permafrost is the result of heat loss from the land surface exceeding the heat input. It follows that, where the mean annual air temperature is 32°F, conditions should be static. Where the average temperature is below 32°F, permafrost should reach some depth depending upon how many degrees below 32°F the average temperature reaches. In reality, theory and fact do not agree exactly for the presence or absence of permafrost, and its depth is related to topography and the nature of the topsoil and other ground cover. It might be noted that the limit of discontinuous permafrost corresponds roughly to the 30°F isotherm and the limit of continuous permafrost corresponds roughly to the 23°F isotherm.

If we assume there is a geothermal gradient of 1°F per 100 feet of depth (as in some mining areas of Ontario), the depth of permafrost at Coppermine River could be over 1,500 feet, and almost the same could prevail in the Ungava nickel belt. There is no certainty that the geothermal gradient in the far north will be the same as in Ontario; however, the great depth to which permafrost can penetrate is indicated.

The question arises as to how permafrost affects rocks and whether the effects will seriously hinder mining. In permafrost, the groundwater is frozen, completely filling the cracks. The net visible effect is greater apparent competence with little tendency to create local "loose". An instance is known of a drummy roof being stabilized by spraying it with a sludge which froze in place.

Rocks in permafrost are stronger than the same rocks when unfrozen. If rock in permafrost is slowly heated, it loses some strength; if heating from the ambient temperature is rapid, some grains fracture and the rock is thereby weakened. If permafrost contains a large amount of ice, as may occur in poorly drained granular materials, it will creep under load, much as ice will.

At present, there are three Canadian mines operating within the zone of continuous permafrost, as defined, and twelve within the zone of discontinuous permafrost. Little is heard from these mines about particular problems due to permafrost. During its brief period of operation, the North Rankin Nickel mine at Rankin Inlet was completely in permafrost, but the total working depth was only about 300 feet. The Tundra mine, northeast of Yellowknife, operated to a depth of over 1,200 feet. Permafrost was experienced here to about 1,000 feet. In the Elsa mine and at Giant Yellowknife, permafrost was encountered between 200 and 300 feet. In these mines, the only obvious problems were with surface buildings. In one instance, the foundation of a mill building settled differentially and cracked seriously. In another instance, sidewalks and roads of a modern townsite settled. In all of the mine workings, no particular steps were taken to counteract the effects of permafrost. The mines gradually warmed up under the influence of heated ventilating air and other mine activity; permafrost thawed into the walls, and southern methods were modified as far as was necessary.

EXPLORATION AND DEVELOPMENT

Techniques of exploration in the North are now well documented. It is known that claim staking is more easily accomplished during freezing weather, inasmuch as frozen muskeg is capable of supporting heavy loads. Winter operations can, therefore, be conducted where summer activities would be extremely difficult if not impossible. Prospecting does not require very large crews and such personnel as are prepared to continue these activities during the winter are usually hardier than the average. However, even hardy individuals will be exhausted by long periods of cold weather activity, therefore comfortable camps must be provided.

Exploration drilling has already been widely pursued in the North, some of this in permafrost. The earliest exploration drilling operations were approached with the thought that heated flushing fluids would be necessary for success. These attempts were soon abandoned when it was discovered that thawing created other problems. As far as is known, heated flushing fluids are no longer used. Current practice leans towards the use of about 1 lb of calcium chloride per gallon of water for flushing solution. This lowers the freezing point to about 25^{o}F and prevents freezing

in the hole. In one location, cores, 12 inches in diameter were taken during a short-hole drilling program. Solutions of calcium chloride were used for flushing, but it was found that 20 percent of the driller's time was spent preparing solutions. Later, when a 200-ft hole was required, only clear water was used for flushing. However, some salt was poured into the hole when the rods were withdrawn. In other locations, successful use of diesel fuel or kerosene as flushing media were reported. A problem with petroleum base flushing media is their ability to dissolve rod grease, and thereby promote seizing up of the joints.

From the accumulated experience outlined above and from other exploration drilling projects, it is noted that early operators were unduly concerned about flushing liquids freezing up. It is generally agreed, however, that a stationary string of drill rods cannot be left in the hole when drilling is stopped for a period.

While northern drilling is in progress, protection must be provided for the crew if a reasonable degree of efficiency is to be maintained. Low temperature is not the sole cause of human discomfort. Protection against wind chill is extremely important, particularly in areas where natural protection is absent.

In development and construction projects, two major courses of action are available: continuous activity, or intermittent, seasonal activity. Camps and supply networks must be established to service all operations. These facilities represent sizeable capital investments whose overall cost will be minimized if their use is continuous.

Efficiency of work crews will be lower during the winter but availability of more highly skilled workmen will partly offset this. During seasonal operations, efficiency of workmen will be higher but expensive facilities will be unused during part of the year. The charges against unused services, combined with costs of shutting down and starting up will become appreciable. One experienced operator found it preferable to carefully select the timing for starting a project (related to shipping restrictions and time for foundation pouring and closing in), then to continue without pause until the project was completed.

Techniques of construction specifically for the northern environment have been well researched, as have the problems of water supply and waste disposal. Only studies of waste disposal have not brought forth completely satisfactory solutions.

SURFACE MINING

Ore and Waste Breaking

Mechanical operation of drills should present no unusual problems in northern surface mining. Surface drills have already been widely used in zones of discontinuous permafrost with only minor modifications from southern procedures.

A Swedish mining company operating North of the Arctic Circle uses a thinner-than-normal oil in all drills and fills them with warmed oil before starting up in the morning.

At Pine Point, some difficulty was initially experienced with hydraulic fluids in drills. The problems were overcome by using automatic transmission fluid Type A diluted with one part in four of P-40 diesel fuel.

In the mines of the Iron Ore Company of Canada Limited, lubricants used in drills were modified and tanner gas was used in air lines.

At the Quebec Cartier Mining Company operations, it was found that drill productivity increased during cold weather. This was attributed to reduction of wet holes from 90 percent to 20 percent.

As far as is known, no unusual problems occur at the bit-rock interface during drilling in the northern Canadian mines. Air flushing is commonly used and this presents no problems in the cold. However, it has been noted that holes through overburden in permafrost are not as subject to caving as holes through unfrozen terrain.

It can be reasoned that blasting should be more difficult in permafrost than in unfrozen rock. The additional blasting costs are usually not noticed in normal surface mining, possibly because other problems loom larger. Only the Iron Ore Company of Canada has reported some methodical research on this problem. The company found that explosives requirements were considerably greater when breaking frozen rock. The increase was even greater when frozen overburden was blasted.

Loading

Loading of broken material is not affected by permafrost per se, but by the ambient temperature and wind conditions. During the initial northern mining operations in Canada, it was found that shovel booms and dipper sticks were susceptible to fracturing in the intense cold. Several solutions have been successfully applied towards meeting this problem. The major improvement has been substitution of T 1 alloys for structural steel in booms and dipper sticks. In addition, the critical parts are "Magnafluxed" before the winter sets in so that any cracks which are discovered can be repaired under favourable conditions. Other measures which have been applied are provision of electrical heating to critical parts and graphitic lubricants.

Operating of loading equipment in extremely cold weather is uncomfortable for men, therefore, cabs are insulated and heated. While a shovel is actually loading, certain parts become heated and operate satisfactorily. But even if a shovel is loading, the propulsion gear train is stationary and sudden starting creates serious strains. One mining company has incorporated an automatic 5-second delay in the starting systems of shovel propulsion gear trains.

Haulage

Initial problems with respect to haulage operations in extreme cold were quickly overcome by mine operators in cooperation with equipment manufacturers. Major modifications which have been made to trucks include use of higher alloys for boxes and adoption of design options to combat the cold. Thinner oils and greases are used for lubrication. Freezing of ore to box surfaces has been overcome by using the exhaust gases from the engine for heating. Numerous cold weather options are now available on haulage equipment and mine operators commonly order them when purchasing. Available are, insulated operators' cabs with fresh air heaters, window defrosters, thermatic radiators (shutters), thermatic fans and engine hood side guards. The operators usually add to the cab insulation by installing padded floor and wall coverings.

During cold weather, excellent haulage roads can be easily maintained, appreciably aiding the mining operation. Dressings of crushed rock are usually used to provide excellent traction. Appreciable increases in tire life have been reported, greatly improving cost performance. One northern operator claims that total winter mining costs are lower than in summer owing principally to reduced haulage costs. As haulage costs are usually 30 to 50 per cent of total mine operating costs, improved haulage is quickly reflected in lower total costs.

During spring breakup and winter freeze-up, serious problems are often encountered with run-off water which freezes during drops in temperature. Where permafrost is present, breakup problems are intensified by poor drainage, therefore, mine operators must provide adequate ditching and continuous road maintenance. Under certain conditions of thawing and freezing, calcium chloride is effective in preventing ice buildup.

Haulage by means other than trucks must be suitably adapted to the existing conditions. For example, if surface conveyors are used, the entire system must be kept either covered and heated or kept cold. If a cold system is selected, the ore must be kept dry to avoid icing-up. Belts of synthetic rubber become inflexible in the cold so natural rubber must be selected. There must also be careful attention paid to selection of oils and greases. Parts of the conveyor installation may be fabricated from special alloy steels, but this could double the cost of the conveyor support structure.

If conveyors must be shifted during the winter, provision must be made for this by mounting them on wood blocks so that movement will be possible when desired. An alternative suggestion applicable to very heavy installations is to mount them on pontoons with built in ducts for circulation of heating air when movement is contemplated. By careful selection of materials and procedure, there is no difficulty in operating conveying equipment to -40 ^{o}F, however, some increase in operating power is to be expected.

Equipment Maintenance

The most important function, that of maintenance of large equipment, is no different whether permafrost is present or not; only the cold is important. As mentioned previously, an important procedure is to apply sufficient foresight so that major scheduled repairs are done before the worst cold sets in. General maintenance of all equipment is simplified where sufficient storage space is available so that equipment not actually in use can be placed in heated storage. The worst condition occurs when equipment, standing idle for a long period in the cold, is started up.

Despite good maintenance schedules which take the climate into account, breakdowns due to unforseen conditions do occur and repairs must be made in spite of the weather. Welding is exceptionally difficult during intense cold. The procedure then is to move the equipment to a heated shop for repairs. It may not be possible to do so, depending on the nature of the particular breakdown. The usual procedure is to provide some temporary protection for the maintenance crew while the equipment is made mobile, then towed into a shop for completion of repairs. This procedure is not possible where the equipment is very large, i.e., a

shovel. The only alternative in this case is to construct a temporary cover over the equipment, provide heat within, and complete the repairs.

UNDERGROUND MINING

General

Some experience has been gained from underground mining in the discontinuous permafrost zone and in two mines operated in the zone of continuous permafrost. No insurmountable problems have arisen. As has been observed, operations in permafrost are cool, dry, and generally more effective than operations without permafrost. The air temperature in the mine is approximately 20°F. The haulageway walls are often covered with ice resembling "hoar frost" instead of the familiar drops of water.

Where ventilating air is heated, the air temperature slowly rises and the permafrost thaws into the walls. At the lower boundary of the permafrost, the ice (if any) in the cracks slowly melts, causing the permafrost to slowly retreat upwards. This boundary area is usually wet and constant attention must be given to local "loose" which appears as thawing progresses.

If a mine is permitted to gradually heat up (usually because of heated ventilating air and normal activity) there will be no particular problem with freezing of pipelines and of broken ore. The alternative would be to keep the mine cool so that the permafrost does not melt. This course would be contrary to current practice and probably would not be approved by mine inspectorates.

Drilling

Drilling in permafrost should not be appreciably different from drilling where there is no permafrost. From a drilling and maintenance point of view, a temperature of about 20°F should not be significant. Even where temperatures are considerably lower, only slight modifications to lubrication practices will be required. In all Canadian underground mines (except some industrial-mineral and coal mines) water flushing of drill sludge is standard practice. At freezing temperatures, excess water would be undesirable so some thought might be given to using presently available dry drills which gather cuttings by suction.

One mining company has introduced saline water into mine water lines in order to prevent freezing. In the same mine, air line freezing was prevented by adding regularly, a small amount of methyl hydrate into the lines.

It is known that dry drilling, with cuttings collected by vacuum, is perfectly workable and that it does not wet the ore. Water is normally required for allaying the dust from blasting and loading, however, some South African mining companies eliminate water and condition the air in deep, hot mines to establish working comfort.

There seems to be no reason why ventilation alone couldn't clear out dust and fumes after blasting. In any event, if the permafrost temperature were very low (say in a far northern mine) the use of large quantities of water for drilling and allaying the dust would be undesirable. On the other hand, little research has been done on the clearing of dust and fumes without water. However, it might be noted that dust is cleared from most slusher (scraper) ore transfer drifts by ventilation alone.

If breaking and handling involves a higher explosives consumption for sub-zero surface mining, it is reasonable to expect the same effects in sub-zero underground mines. The northern mine operators have production schedules to meet so they probably haven't had the time to evaluate the effects of permafrost on blasting. One would expect that, in development openings, no extra explosives would be required because of the permafrost because these blasts are usually overcharged with explosives, whereas in stopes, where minimum powder factors are normally used, the increased requirement in permafrost might be appreciable. A mine in permafrost would probably never achieve an explosives consumption as low as in southern locations.

Support

The size of locally grown timber decreases as one moves northward. North of the tree growth line, there will of course be no timber at all. Under average conditions, it would not be practical to import bulky timber from southern locations for any but special applications such as shaft timbering and chutes unless the point of use is close to a seaport.

Fortunately, rock bolting is an economical way of retaining roofs and walls and because of their low bulk, bolts are easy to transport. Re-usable steel sets may have some advantages for northern locations. A wider use of concrete is another possibility.

In the Canadian mining industry, about 20 per cent of the ores are mined by cut-and-fill stoping or related methods. There is little doubt that deslimed tailings provide the best type of stope support while solving a disposal problem.

It is known that mines kept cool in permafrost are unlikely to develop local "loose" as readily as mines without permafrost. Further, as stoping methods which involve broken material storage (i.e. shrinkage) may be less suitable for mines in permafrost, methods which require less support, such as sublevel caving, may be more frequently used. It is possible, therefore, that considerably less support will be required in permafrost than elsewhere. Whether this is the case or not, cannot be evaluated without more research on the stability of frozen ground.

A novel method of using ice to support openings in surface and underground mines in cold climates has been proposed for a location in Norway. By the proposed method, only the ore would be mined from surface and the opening would be filled with ice to support the walls. After reaching the economic depth of surface mining, operations would be transferred underground and mining continued by the sublevel stoping method. Practically no waste would be mined.

As underground mining proceeds by a retreating system, ice is expected to flow into the openings, thereby supporting the wallrocks. It is known that pure ice will flow as mountain glaciers do, therefore more ice would be made on surface during freezing weather, on top of the ice mass to compensate for the volume of ore extracted and for the ice lost through melting. By keeping the mine cold, the requirement for make-up ice would be kept to a minimum. As far as is known, the method is not yet in operation.

Thoughts of using ice as a support recalls a proposal to ice-fill the stopes in the North Rankin Nickel mine. The proposal was never implemented because sufficient gravel could be obtained from eskers during the short summer. Because ice and frozen gravels in permafrost creep under load, pure ice could not be expected to be a good support medium in a mining method where the support must remain static (i.e. in a filled stope). This raises the question as to whether hydraulically placed classified tailings, normally placed at about 60 per cent solids, would be satisfactory fill if frozen in place without draining. It is known that pure ice will flow under load and that frozen gravels and silts with high water content will creep under load but that frozen rocks are stable and competent. There must be a frozen mixture of ice and rock that would behave sufficiently like a solid to function as fill.

Materials Handling

Whether a mine is in permafrost or not, should not affect the efficiency of loading. However, if the mine is to be kept cold, the usual practice of using large quantities of water for wetting down cannot be followed. In a cold mine, heated cabs under positive air pressure could be provided for the crews. However, dry muckpiles produce dust which affects visibility, therefore, adequate ventilation must be relied upon to clear the air.

Within a mine in permafrost, it would be impossible to store either ore or waste in ore passes or other openings. At Rankin Inlet, gravel fill was obtained from eskers during the short summers. The gravel was very wet and when dumped down a fill raise, tended to freeze. The problem was solved by keeping the fill raise empty and dumping only small batches of gravel at a time. If the gravel didn't reach the bottom, remedial measures could be taken before the raise was clogged. After a period of fill dumping, the permafrost thawed into the walls of the raise and the rate of dumping could be increased.

Haulage in permafrost should not be appreciably different from haulage elsewhere. It is true that some early experience with certain battery locomotives revealed deficiencies in resistance to cold. These initial problems have been overcome. However, trolley-type and diesel locomotives should operate perfectly satisfactorily.

Haulage tracks are stable in a permafrost zone. Where local areas of instability occur, some wet sludge poured over the ties acts as an excellent stabilizer upon freezing.

Wherever rock is hauled, there is a tendency for fines to build up in mine cars. This is usually overcome by manual cleaning, sometimes aided with blowpipes. The extent of buildup in mine cars varies with the type of material hauled, its moisture content, and the type of car. In general, fines tend to build up more in ramp-dumped cars than in rotary-dumped cars. In southern mine operations, where buildup of fines in cars tended to become serious, cylinder-dumping while cars are stationary has been adopted to ensure better emptying.

In a cold mine, build-up in cars would be a still more serious problem owing to freezing. This may be minimized by carefully selecting the car and dumping system. However, if build-up of fines continues, a sprinkling of salt in the empty cars will reduce the tendency. Other measures would be required to combat corrosion.

Build-up is usually less in loader buckets than in mine cars because of the scouring action of the ore on the bucket during loading and the vigorous dumping. In a cold environment, icing up may still occur. The only way of avoiding this appears to be by keeping the ore as dry as possible and by periodic clean-up.

Underground conveyor haulage is a practical and efficient way of moving crushed ore underground. An underground conveyor may be easier to operate than one on surface. However, as on surface, the product which is transported will have to be kept dry and cold or the whole conveyor system will have to be heated.

Maintenance

Maintenance problems in northern underground mining are less serious than those in surface mining. Mine hoists and other surface installations are usually in heated buildings, therefore maintenance will be comparatively easy.

The trend in northern locations is to provide services in one large building or to connect separate service buildings together by tunnel so that underground or other equipment will never have to be repaired outdoors.

It has been shown that all equipment can be repaired in underground shops without having to bring it out of the mine. Typical examples are the underground repair facilities in the Port Radium mine at Great Bear Lake. If such shops must be located in permafrost, research has already shown that polyurethane insulation sprayed on the walls will enable the shops to be heated without destroying the permafrost in the surrounding rock.

An icing problem arises when moisture laden air is passed through shafts and ventilation raises in the winter. In Canadian mining, upcast air flow is usually preferred for production shafts and downcast flow for ventilation raises from surface. This has usually been done to reduce icing problems in production shafts. Some methodical study of the icing problem appears to be warranted because it causes more difficulties than is generally known.

CONCENTRATE HANDLING AND SHIPPING

It is known that the recoveries during milling are affected by the temperature of the process water. The common method of raising the temperature and thereby improving recoveries is to use waste heat to the extent that it is available. Cooling water from air compressors is a usual source of waste heat in northern operations.

Except in gold mines, a concentrate is ultimately produced for shipment to a smelter. It may be decided to use containers as is now done in all the Yukon operations. In other areas, rail cars or bulk loaded trucks may be used. A decision must be made whether to ship wet from a cold location and thaw at destination or to dry the product before shipment. Considerable experience has now been gained in shipments from Lynn Lake, Pine Point, and Quebec-Labrador.

Run-of-mine ore from the Snow Lake area is shipped to Flin Flon without drying. The average temperature from October to April is 4°F but it may be 50° colder. Trains of twelve 32-cubic-yard cars are thawed and emptied by rolling dumpers in the thaw sheds at Flin Flon. Six direct-fired oil heaters, each capable of 2 million Btu/hr were operated for 300 to 400 hours per year. Time required to thaw a train was about 4 hours, and thawing costs were 3 cents a ton.

At Lynn Lake, concentrates are dried to 3 per cent moisture in oil-fired dryers, whereas at Quebec Cartier, the final moisture content is about 1 per cent after passing through fluo-solids dryers fired with bunker C oil. At Pine Point, concentrates are dried to 3 per cent moisture content in a butane-fired dryer.

The methods of drying (and thawing) concentrates which have already been worked out at the existing northern operating mines will no doubt be applied to new operations which start up. Some thawing units based on infra-red heaters will also be used. One of the major advantages of drying before shipping is the saving in freight charges. It is reasonable to expect this to become more important as the distances become greater.

SUMMARY

Experience has shown that both surface and underground mining can be pursued in the northern environment with only slight modifications to the mining technology of temperate regions being necessary. The modifications are made necessary by low ambient temperatures, which have the greatest effect in surface mines. Underground mining has not been hampered to the same extent owing to the protection provided by the workings.

If mining in the North and in permafrost continues to grow (as it surely must), the operations would prosper more if methods can be developed which are most efficient in such an environment.

In surface mining, one problem which may require methodical research is that of fragmenting frozen ore.

In underground mining, one of two basic approaches could be selected: (a) to mine as in southern locations and make modifications as they arise and, (b), to accept the northern conditions, including the permafrost, and endeavour to utilize whatever advantage it presents. If the first alternative is adopted, the required adaptations can probably be made by the operators themselves. The second alternative cannot be adopted without some fairly fundamental studies.

The following are areas in which research may aid northern mine operators to achieve lower costs:

(1) fragmenting frozen rock,
(2) properties of frozen rocks, including stability in mine openings,
(3) properties of frozen fills of various compositions,
(4) environmental and economic effects of dry mining, and
(5) preventing icing-up of shafts and other mine workings.

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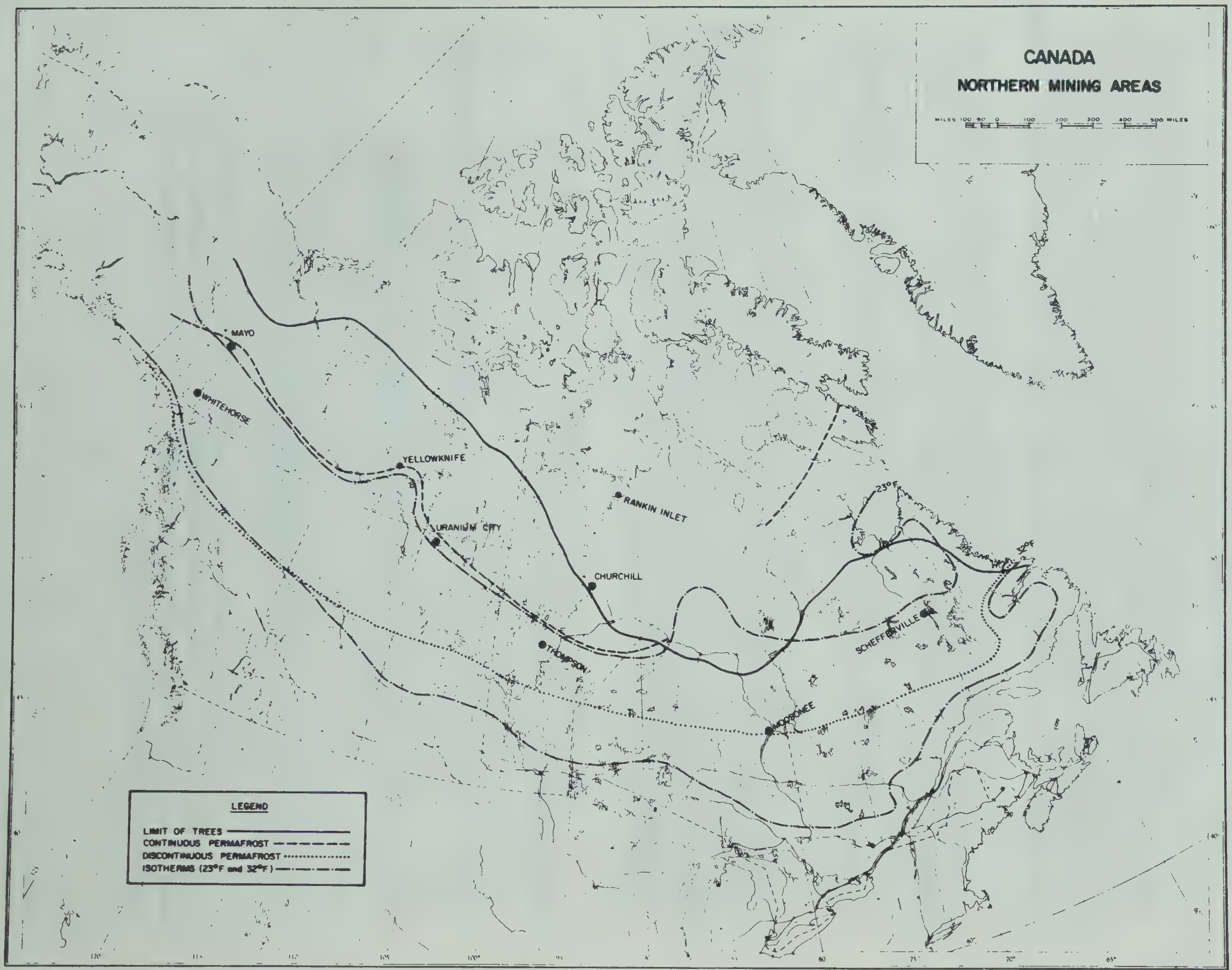

Figure 1 - Northern Mining Areas

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